Modeling Methodology for Custom Design Storms in Eastern Washington

By Anthony O. Righellis, P.E.
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1.0   Introduction

The purpose of this study is to identify the best modeling approach for (1) using custom design storms to size runoff treatment facilities in eastern Washington and (2) meeting environmental objectives for flow control as determined in a concurrent effort. This scope can be performed in varying degrees of detail. For this undertaking a 'big picture' approach was implemented with a labor effort commensurate with that approach.

2.0   Storm Types

Three storm types are considered.

Short-Duration Storm (3 hour) -- This storm is intended to represent a summer thundershower.

SCS Type II Storm (24 hour) -- This is the standard storm pattern established by the Soil Conservation Service for Eastern Washington. It is recognized that this is not the only storm pattern that can occur. It is the storm pattern that was designated in an era when sizing conveyance facilities (pipes, culverts, channels, and bridges) was the near sole consideration, thus using that storm type produced the maximum peak flow rate.

Long-Duration Storm (72 hour) -- This storm is intended to represent a winter rainfall.

3.0   Peer Review of Custom Design Storms Developed by MG Schaefer

The custom design storms developed by Schaefer appear appropriate in temporal pattern. The short-duration and SCS Type II storms hyetographs are common patterns utilized in arid regions. They are patterns characterized by intense rainfall over relatively short periods within their duration.

The four regional long-duration storm hyetographs do not appear like the majority of the 57 gauged precipitation events used to create the four hyetographs. The gauged multiple peaks appear random. They vary in relative size from small to large, large to small, and sometimes similar. The spacing between peaks varies significantly. From a macro pattern perspective, the long-duration storm hyetographs appear appropriate, but implementation is a concern. Event-based runoff modeling is time dependent, thus hyetograph shape is an important parameter.

The custom design storms developed by Schaefer appear appropriate in intensities. This conclusion is based on a spot check of an available precipitation gage for a recent seven-year period. Although this is not definitive proof for all locations and storm events, it does provide indication that the precipitation maps and adjustment equations are reasonable.

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4.0   Literature Review and Hydrologic Experts Consultation

Literature review and hydrologic experts consultation was attempted with emphasis on the long-duration storm.

Arid-region data relating precipitation to runoff flow rate and volume appears non-existent for small-time increments (15 minute, 30-minute, hourly, etc.). Calibration and sensitivity analyses of any computational method are neither readily available nor doable due to the lack of small time-increment data.

Literature, other than the work prepared by and cited by Schaefer, appears non-existent for arid region long-duration storms. The same appears true for experts. Web-based searches to find directly relevant information including the use of small time increment multiple peak hyetographs were made but nothing relevant was found.

5.0   Methods to Estimate Runoff Volumes and Flow Rates

There are a variety of computational methods available for computing runoff volumes and peak flow rates. Schaefer prepared a methods review (November 7, 2002). The final conclusion in that document is fully agreed with.

> "Accuracy of uncalibrated runoff estimation methods is generally poor for undeveloped sites in arid and semi-arid environments. Without runoff data for verification, it is not possible to say which of the off-the-shelf runoff estimation methods would likely yield the more accurate results."

Potential methods are Exponential Loss, Green-Ampt, Holtan, Initial Abstraction and Uniform Loss Rate, Soil Moisture Accounting, Hydrological Simulation Program--Fortran (HSPF), Natural Resources Conservation Service (NRCS) Runoff Curve Number Method, Rational Method, and Regression Equations. Many of these methods could be appropriate for long-duration runoff modeling if calibrated. Another key recommendation from Schaefer is also agreed with.

> "The selection of runoff estimation methods should be made from commonly used methods that are readily available in computer programs for computation of runoff hydrographs."

Schaefer's list of commonly used methods is broader than what may be commonly used by design engineers that are not hydrologic specialists.

The methods commonly used by regulatory agencies, design professionals, and software vendors are the **SCS Method** (NRCS Runoff Curve Number Method), **Rational Method**, and **Regression Equations.** Without quality rainfall-to-runoff data, only commonly used methods should be considered until data can be collected and calibration efforts performed. With commonly used methods, the expertise of regulatory agencies, design professionals, and software vendors offer the best opportunity to use reasonable input values and produce reasonable output. Thus even though not technically calibrated, results that meet the standard of care for the industry are more likely using common un-calibrated methods than uncommon un-calibrated methods.

6.0   Recommended Hydrologic Modeling Method

Of the three commonly used methods listed above (SCS Method, Rational Method, and Regression Equations), only the **SCS Curve Number Method is recommended** for computing flow rates and runoff volumes for long-duration storms.

The SCS Method is commonly used for small and large basins, though method origins are from large rural basins. The engineering community has experience implementing this method. NRCS states this method is only applicable for single peak hyetographs and should not be applied to multi-peak hyetographs. This restriction makes direct application of the multi-peak long-duration storms a concern that needs to be addressed.

The Rational Method is a good method for computing peak flow rates of small urban basins but has no capability to determine reasonable hydrographs and runoff volumes.

Regression Equations require quality-measured data to create meaningful regression equations. Peak flow rate determination is the common use of regression equations. Runoff volume regression equations appear non-existent. As stated previously data is lacking.

7.0   SCS Method Hydrologic Modeling Approach Discussion

Short-Duration Storm (3 hour) and SCS Type II Storm (24 hour)

The short-duration three-hour storm and the SCS Type II 24-hour storm hyetographs can be directly modeled by readily available hydrologic modeling software and produce intended results.
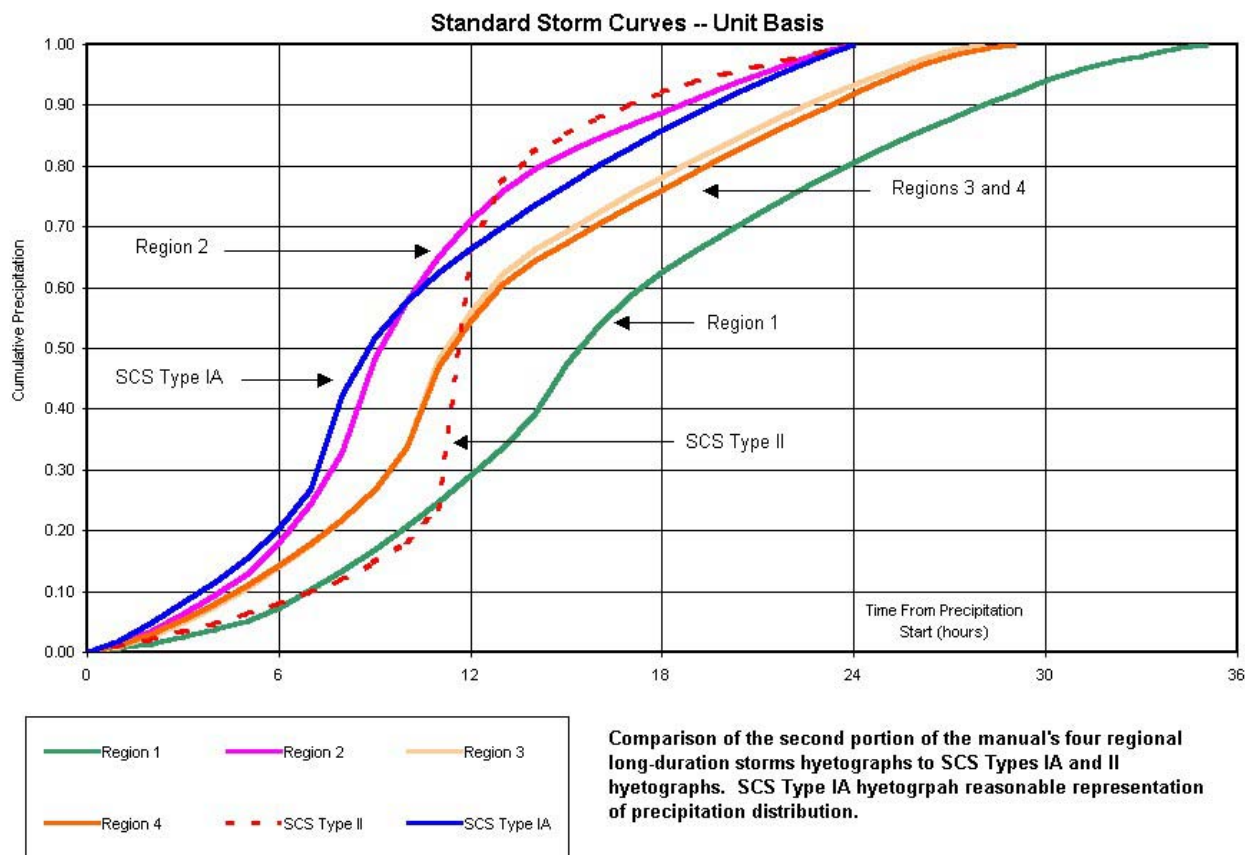
Long-Duration Storm (72 hour)

The multi-peak long-duration storm can also be directly modeled by readily available hydrologic modeling software, but does not necessarily produce intended results. The NRCS has verbally stated that the SCS Method should not be applied to multi-peak hyetographs. From that NRCS caution it was not clear if it was merely an unintended use or if computational inaccuracies were possible. The later appears to be the case as is evident by the sensitivity analysis that was performed and described in the section 9.0.

With this limitation, another approach is necessary to model the long-duration storm hyetographs. Two key characteristics are apparent from the multi-peak long-duration hyetographs established by Schaefer.

(1) The first portion of the four regional hyetographs is diminutive compared to the second portion. The first portion of the hyetograph is only 16% to 25% of the total hyetograph, depending on region. With most Eastern Washington 72-hour precipitation amounts, the precipitation amount in the first portion hyetograph is also diminutive.

(2) The period of no precipitation between the end of the first portion and beginning of the second portion ranges from 12 to 18 hours, depending on region.

These two key characteristics result in hydrographs that have no flow for the entire time between the two hyetographs and sometimes no flow during the first hyetograph. This means there is no compelling reason to directly model the first portion.

With only the second portion needing to be modeled, there becomes a curiosity if that portion of the long-duration storm appears similar to the storm pattern where winter rainfall originates, the coastal region of the state. The SCS storm pattern for that region is the SCS Type IA. Figure 1 shows the four regional long-duration storms as cumulative precipitation for only the second portion of the hyetographs and the SCS Type IA and II 24-hour storms.

Comparison of the second portion of the manual's four regional long-duration storms hyetographs to SCS Types IA and II hyetographs. SCS Type IA hyetogrpah reasonable representation of precipitation distribution.

Figure 1 – Standard Storm Curves

The SCS Type IA storm is similar in shape to the second portion of all four regional long-duration storms. With this similarity, the SCS Type IA may produce acceptable results without the added complexity. The 24-hour duration allows for easy use of the built-in storm pattern feature of most SCS Method software. This reduces potential for computational errors due to incorrect implementation of unique duration hyetographs.

Actual duration analysis provides computations that more directly reflect the second portion of the long-duration storm hyetographs, but those durations are not precise, they are statistical representations. Table 1 shows the key comparisons to the 24-hour storm.

Second Portion of Long-Duration Hyetograph	Region 1	Region 2	Region 3	Region 4
Duration (hours)	35	24	28	29
Duration as Ratio of 24 Hours	1.46	1.00	1.16	1.21
Precipitation as Ratio of 24-Hour Precipitation	1.16	1.00	1.06	1.07

Table 1 – Long-Duration Storm Second Portion Hyetograph Comparisons

Region 1 could be considered for 35-hour duration and 1.16 x 24-hour precipitation storm analysis. Sixteen percent more precipitation spread over 46% more time should produce less peak flow but more runoff volume than SCS Type IA 24-hour storm. Much of the differences compared to the Type IA storm is in the waning hours of the hyetograph, thus would have less impact than might be expected.

Regions 2, 3, and 4 show no or only minor variation from SCS Type IA 24-hour storm, thus use of 24-hour storm is sufficiently accurate.

8.0   SCS Method Hydrologic Modeling Approach Recommendation

Short-Duration Storm (3 hour) and SCS Type II Storm (24 hour)

Modeling of the short-duration three-hour storm and the SCS Type II 24-hour storm are to be per standard methods for those hyetographs.

Long-Duration Storm (72 hour)

The recommended approach for modeling the long-duration storm is as follows.

Rainfall Modeling
Emulate only the second portion of the long-duration storm hyetograph, but account for the first portion.

Rainfall Distribution
Use SCS Type IA 24-hour storm. This provides the simplest modeling approach and reduces the chance for error by implementing a non-standard hyetograph. If a local jurisdiction prefers the added complexity, the second portion of the long-duration storm hyetograph as set by Schaefer can be implemented.

Rainfall Intensity
Use 24-hour intensity if using the SCS Type IA storm. If using the second portion of the long-duration storm hyetograph, use the precipitation ratio in Table 1 above.

Curve Numbers
Adjust Curve Numbers to account for saturation conditions due to first portion of hyetograph that is not directly modeled. Engineering analysis and judgment to be used for Curve Number adjustment depending on soils characteristics, existing surface conditions, and first-portion precipitation amount.

9.0 Sensitivity Analysis of SCS Method Modeling

The primary concern regarding the SCS Method that has arisen in this study effort is the implementation of the multi peak hyetographs. To test the concern, HEC-HMS (Hydrologic Engineering Center – Hydrologic Modeling System) was used to compute hydrographs. Three 25-year event hyetographs were modeled for an eight (8) acre basin with four basin coverage conditions.

Hyetographs (25-Year Event Region 3)
(1) SCS Type IA 24-Hour Storm at 2.1 inches
(2) Long-Duration 72-Hour Storm at 2.8 inches
(3) Long-Duration Second Portion Only Hyetograph
     of 72-Hour Storm at 2.25 inches

Basin Conditions
(1) Curve Number 65
(2) Curve number 75
(3) Curve Number 85
(4) Curve Number 95

Table 2 shows the key results of this analysis. Figures 2 through 13 show the resulting hydrographs of each storm on each basin.

For the 72-hour storm, as the initial loss rate decreases, runoff is generated earlier in the second hyetograph than in the SCS Type IA and second-portion only storm hyetographs. This means there is less initial abstraction (loss) computed in the more critical portion of the 72-hour hyetograph than the other storms. This is counterintuitive as the bulk of the 0.55 inches first-portion hyetograph rainfall occurs 24 hours prior to the start of the second hyetograph, thus there should be opportunity for the entire initial loss to occur again at the start of the second hyetograph.

This initial loss computational difference and the impact it may have on second-portion hydrograph flow rates supports the NRCS contention regarding the modeling of multiple peak hyetographs. The peak flow rates computed in the multi-peak long-duration 72-hour storm do not match well with the peak flow rates computed from the other two hyetographs, as is shown in Table 2.

Eight-Acre Drainage Basin – 25-Year Event – Region 3

Curve Number	65	75	85	95
Initial Loss (inches)	1.08	0.667	0.353	0.105
Peak Flow Rate				
SCS Type IA 24-Hour Storm (cfs)	0.11	0.36	1.5	3.3
Long-Duration 72-Hour Storm (cfs)	0.48	1.2	2.0	2.8
Long-Duration Second Portion Only Hyetograph of 72-Hour Storm (cfs)	0.14	0.55	1.4	2.6
Peak Flow of First-Portion Hyetograph				
Long-Duration 72-Hour Storm (cfs)	0.0	0.0	<0.1	0.6
Runoff Contribution After Precipitation Starts				
SCS Type IA 24-Hour Storm (hours)	9.0	7.5	5.5	2.0
Long-Duration 72-Hour Storm, second portion of multi-peak hyetograph (hours)	9.5	4.0	0.0	0.0
Long-Duration Second Portion Only Hyetograph of 72-Hour Storm (hours)	12.0	10.5	7.5	4.0

Table 2 – Storm Hydrographs Comparisons

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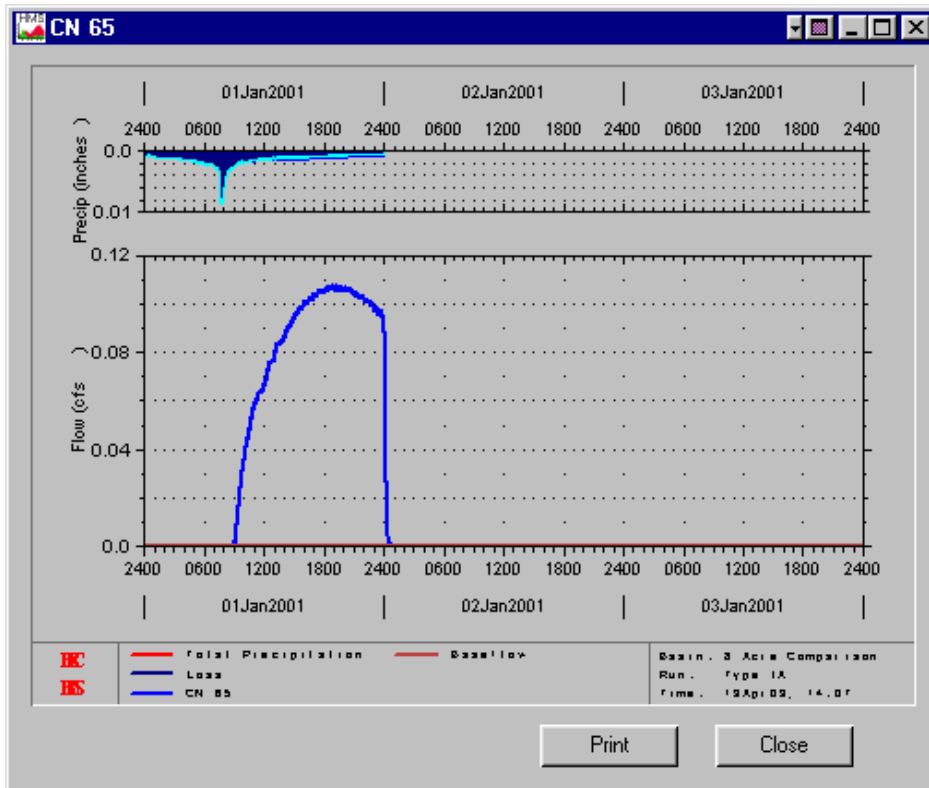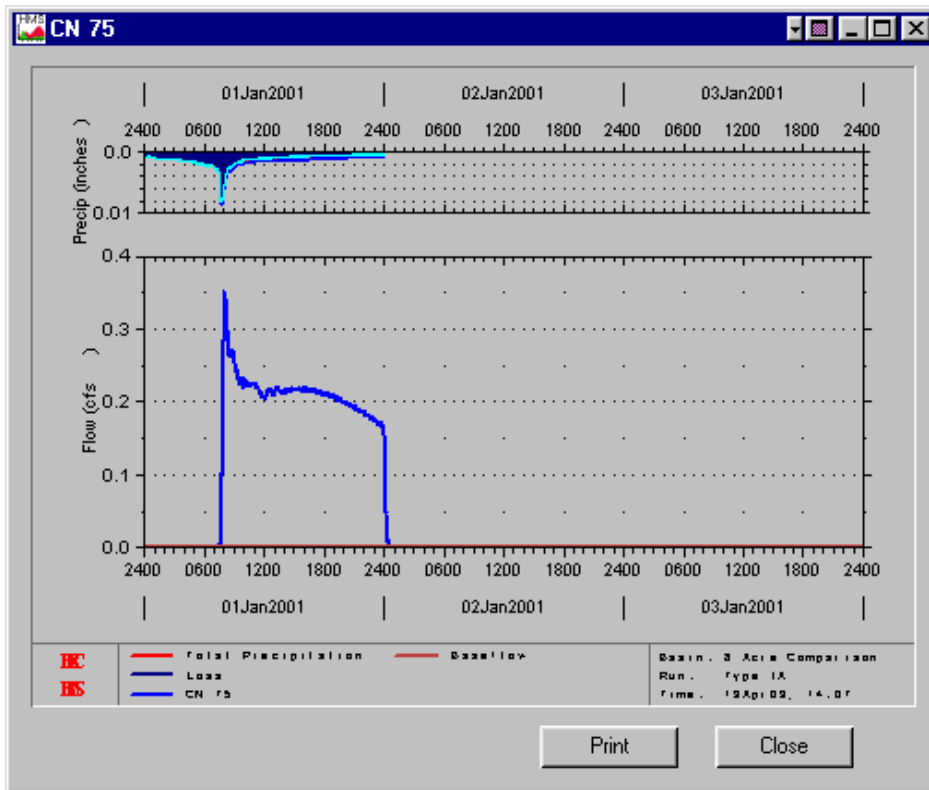May 12, 2003   Page 7 of 14

Figure 2 – Hydrograph for Type IA Storm 8-Acre Basin Curve Number 65

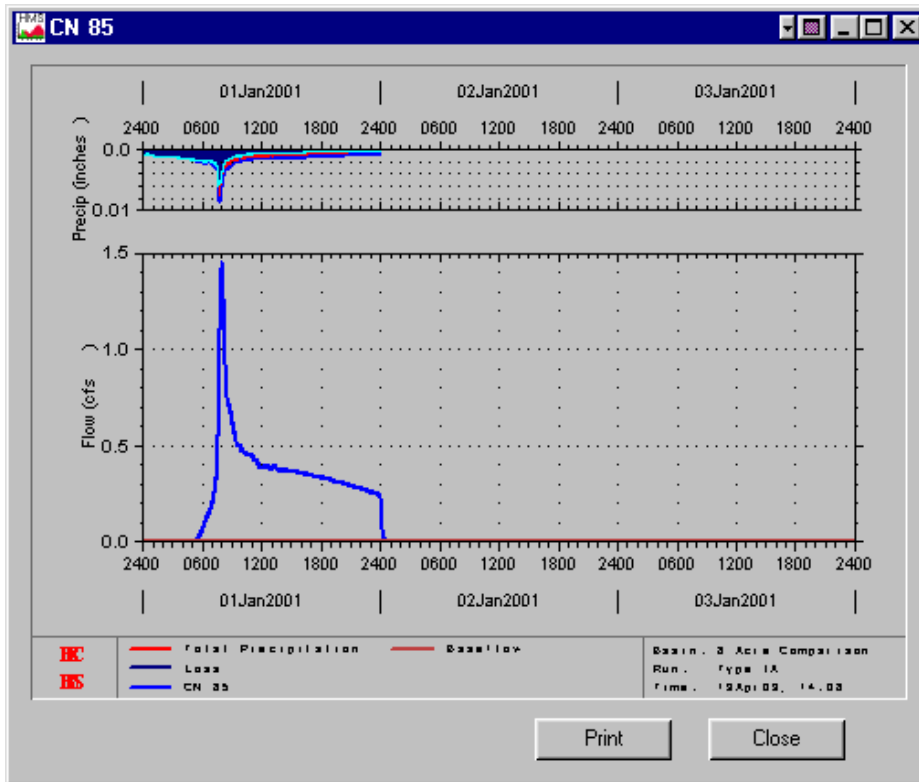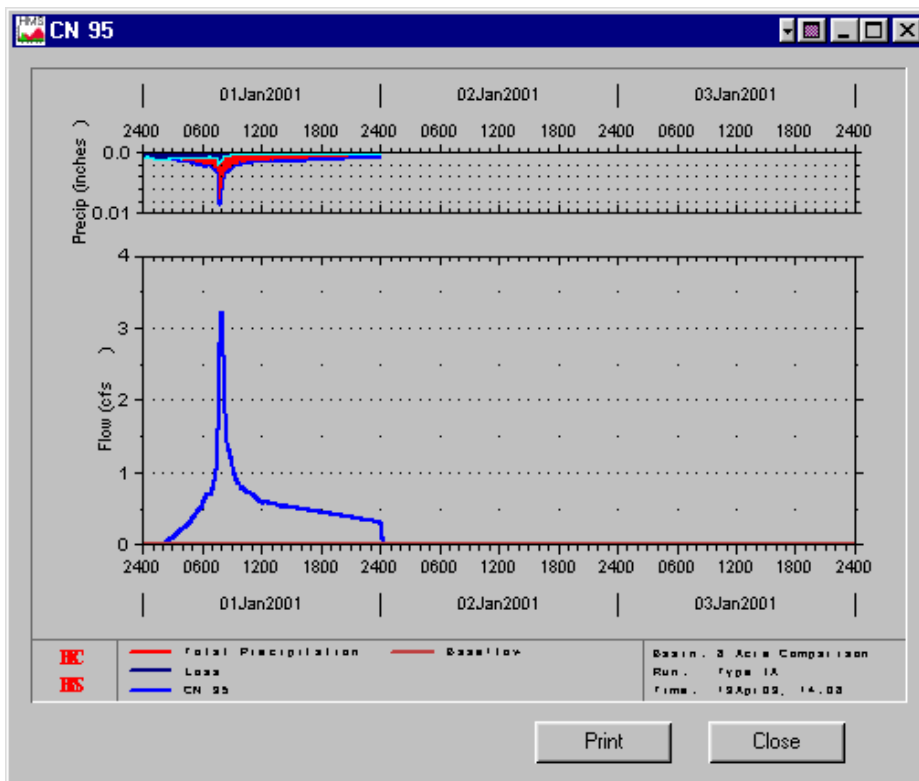*Figure 3 – Hydrograph for Type IA Storm 8-Acre Basin Curve Number 75*

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Figure 4 – Hydrograph for Type IA Storm 8-Acre Basin Curve Number 85

Figure 5 – Hydrograph for Type IA Storm 8-Acre Basin Curve Number 95

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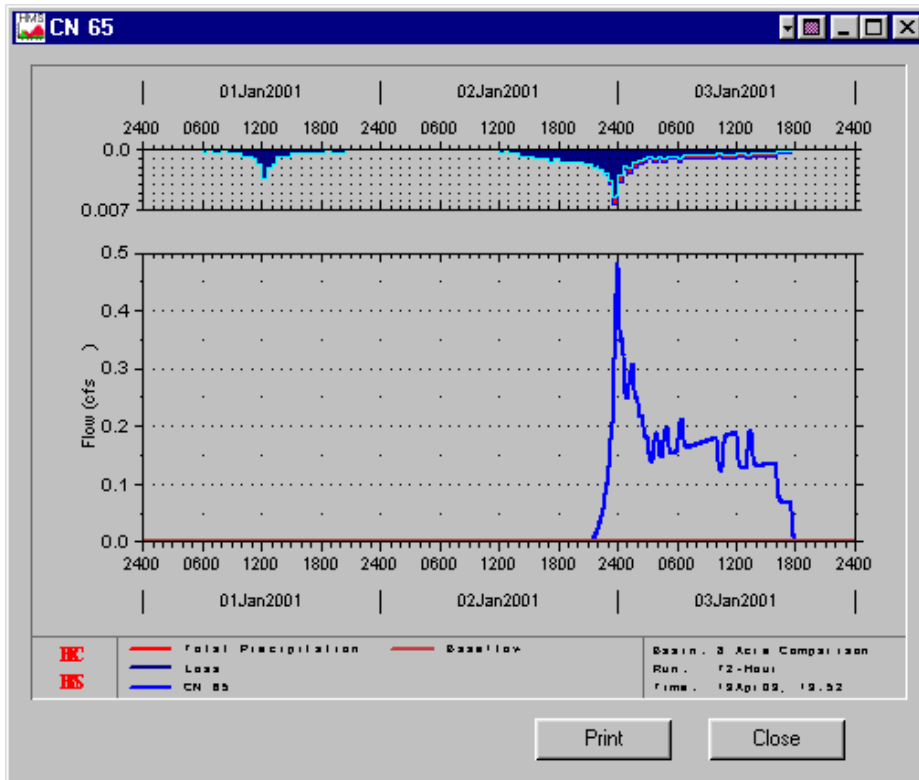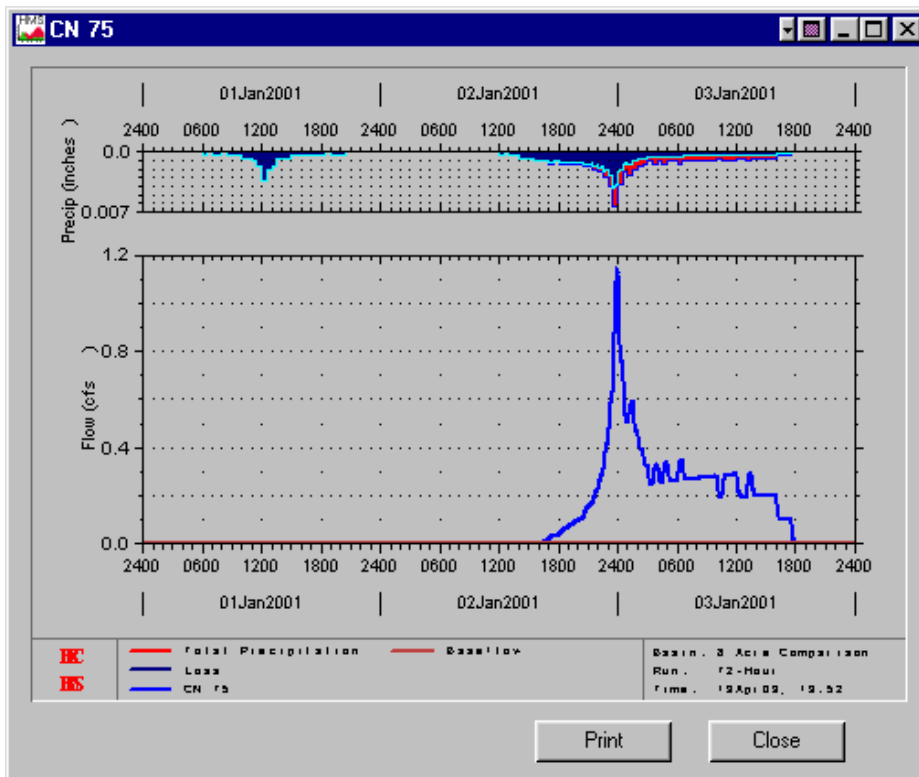By Anthony O. Righellis, P.E. ♦ Harper Houf Righellis, Inc.

Figure 6 – Hydrograph for Long-Duration 72-Hour Storm 8-Acre Basin Curve Number 65

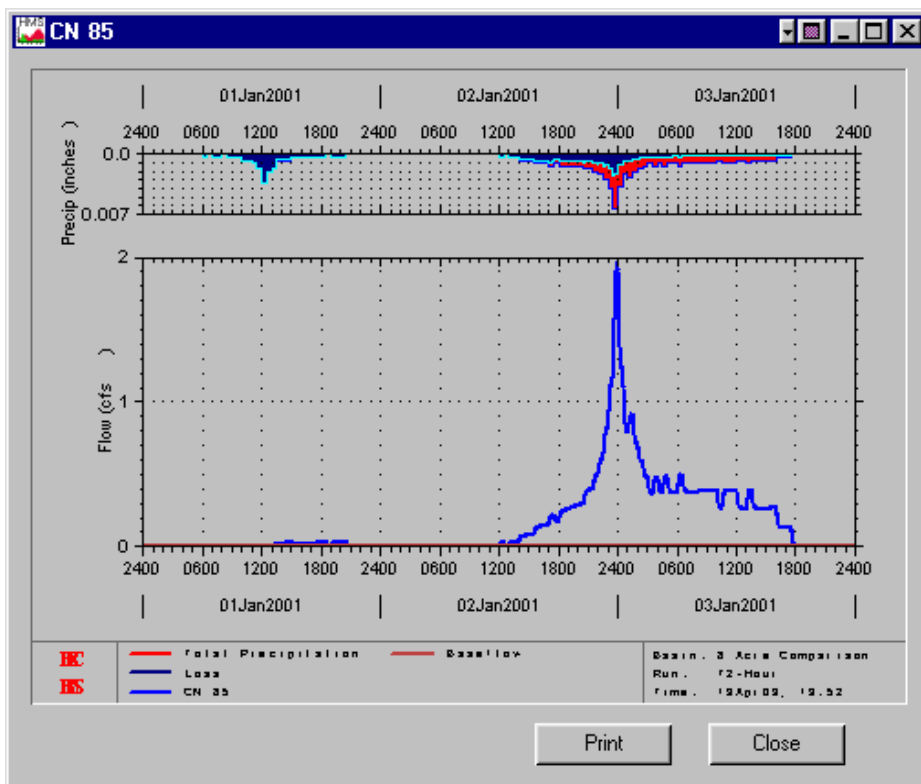*Figure 7 – Hydrograph for Long-Duration 72-Hour Storm 8-Acre Basin Curve Number 75*

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Figure 8 – Hydrograph for Long-Duration 72-Hour Storm 8-Acre Basin Curve Number 85

Figure 9 – Hydrograph for Long-Duration 72-Hour Storm 8-Acre Basin Curve Number 95
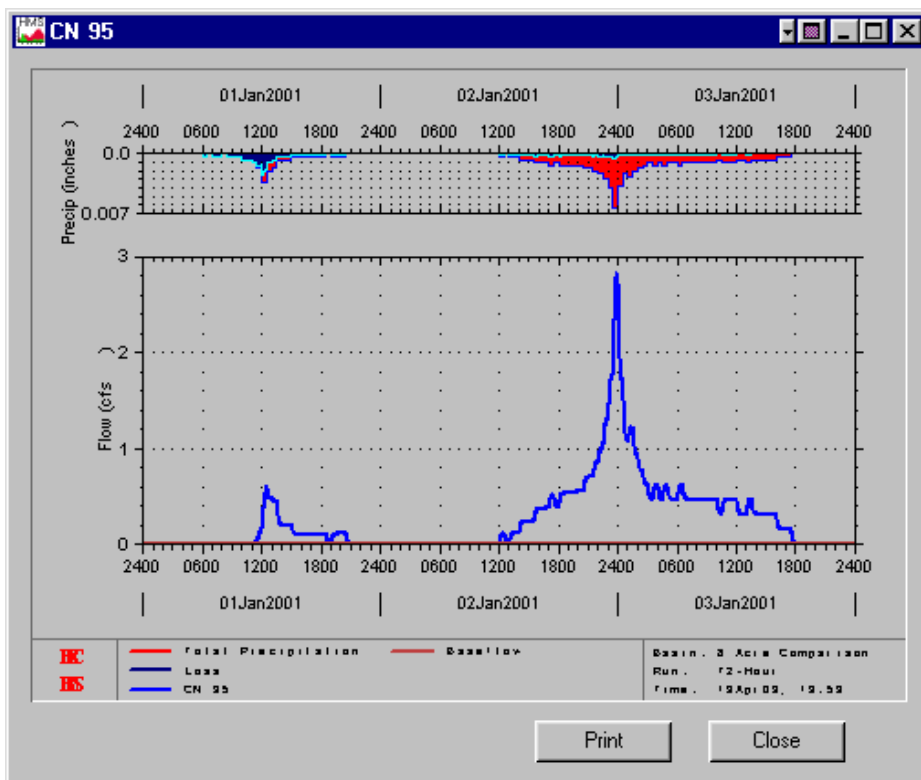
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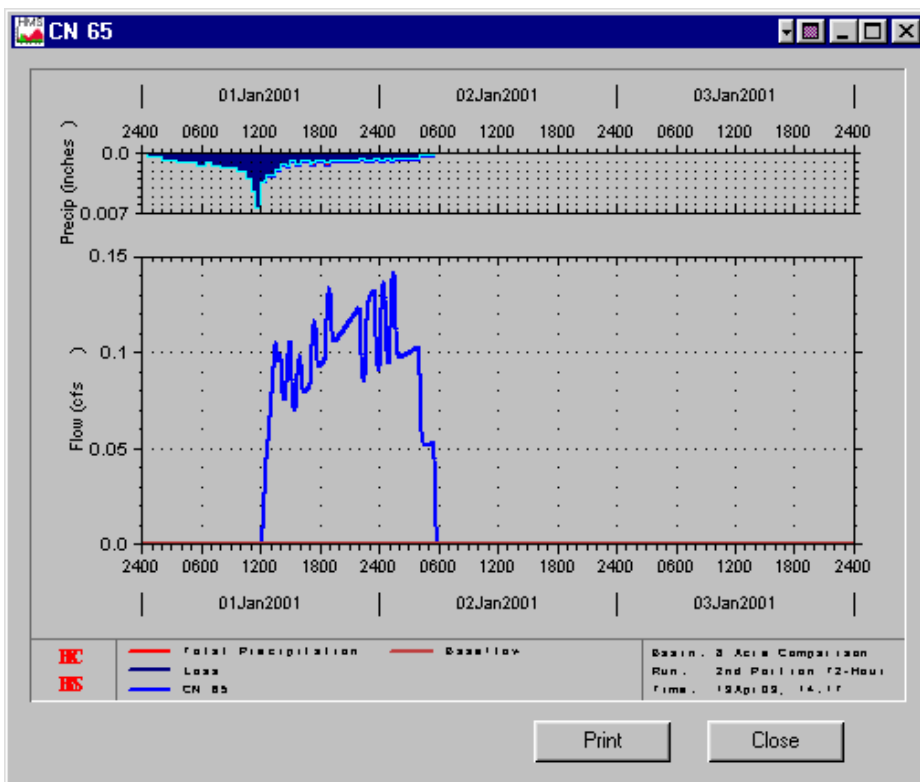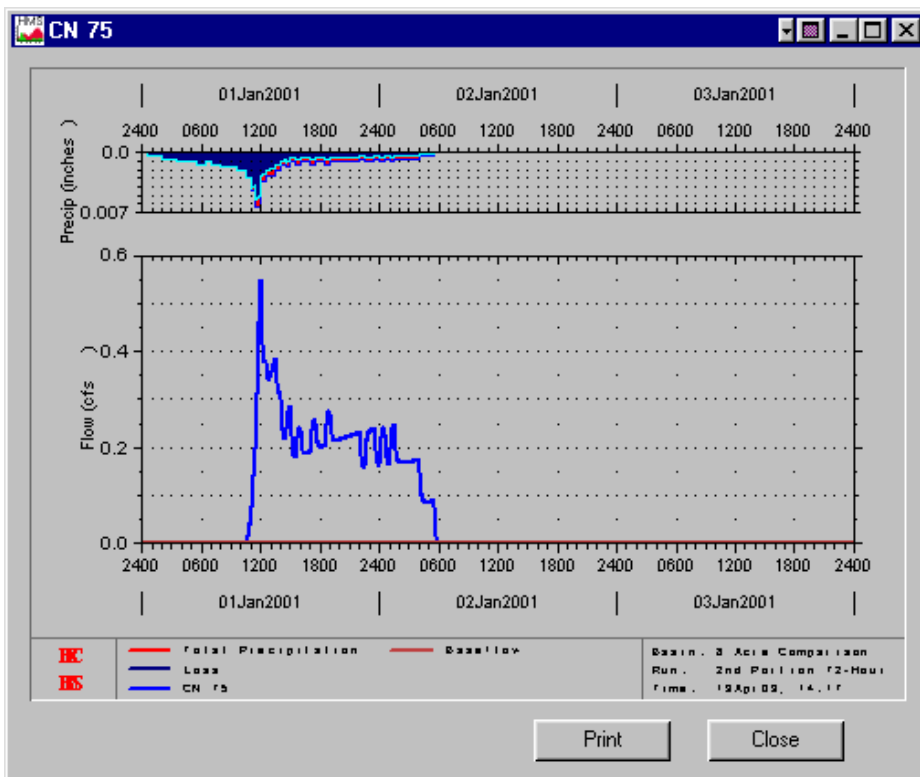By Anthony O. Righellis, P.E. ♦ Harper Houf Righellis, Inc.

Figure 10 – Hydrograph for Long-Duration Second Portion Only Storm 8-Acre Basin Curve Number 65

Figure 11 – Hydrograph for Long-Duration Second Portion Only Storm 8-Acre Basin Curve Number 75

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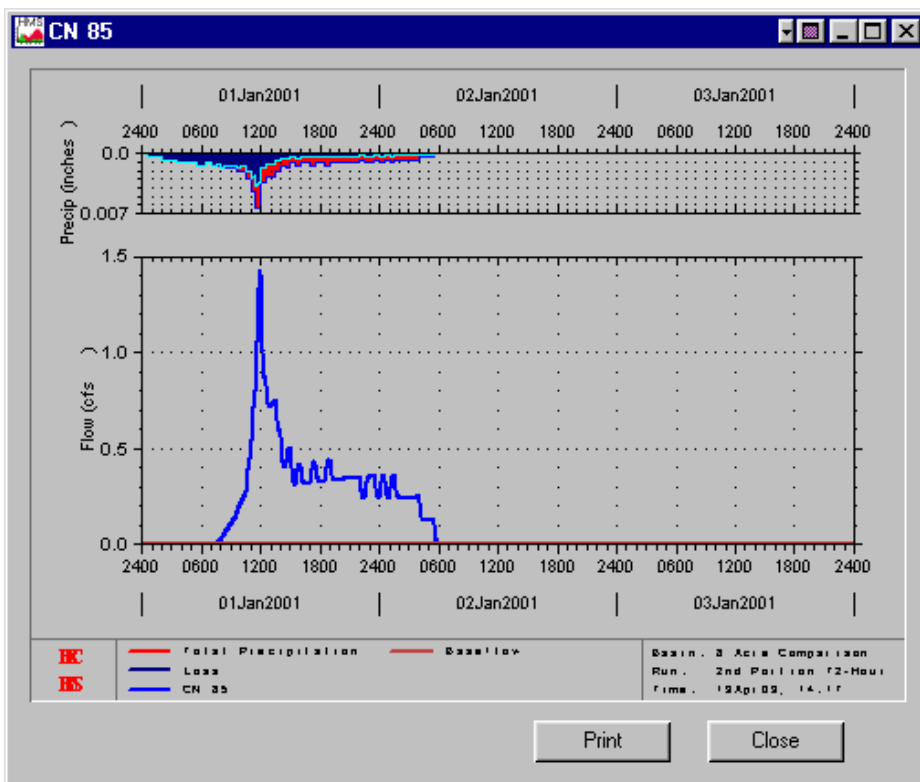By Anthony O. Righellis, P.E. ♦ Harper Houf Righellis, Inc.

Figure 12 – Hydrograph for Long-Duration Second Portion Only Storm 8-Acre Basin Curve Number 85

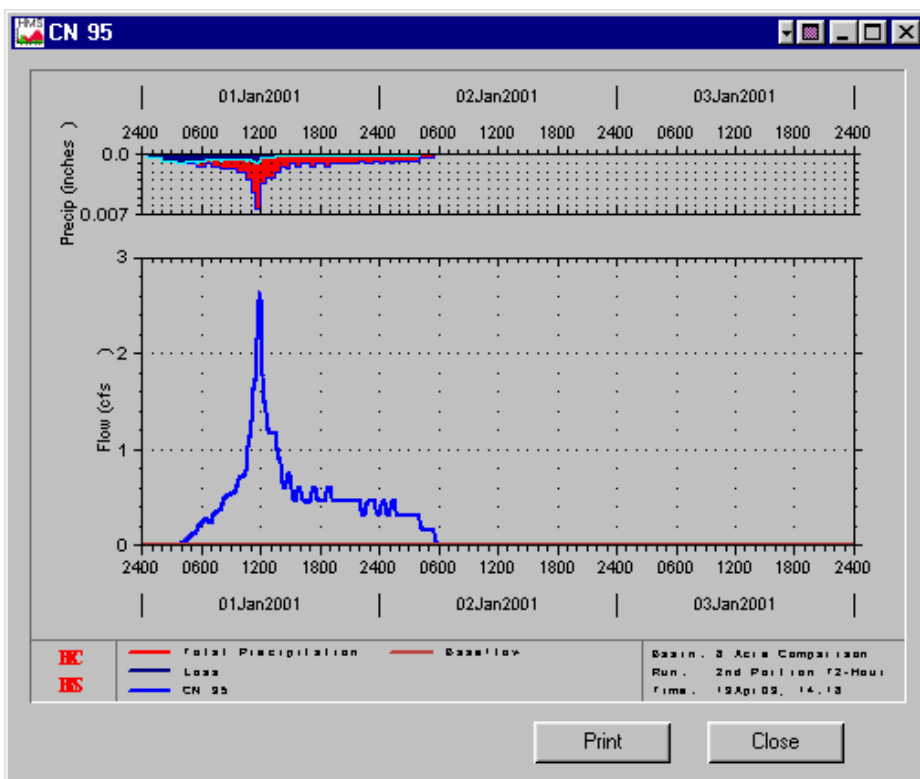*Figure 13 – Hydrograph for Long-Duration Second Portion Only Storm 8-Acre Basin Curve Number 95*

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10.0   Future Data Collection and Analysis Effort

A future effort of rainfall-runoff data collection and modeling correlation should be undertaken. This will improve the best available science beyond what exists today. Precipitation gages that can measure in small time increments should be placed within drainage basins where runoff flows can be measured in similar small time increments.

To be effective, this data collection effort should include broad ranges of drainage basins based on total annual precipitation, elevation, grades, soils types, development types, and degree of development.

Upon storm type segregation, data analysis should include determining computing effective modeling parameters, such as lag times and SCS Curve Numbers, and comparing them to values commonly used.

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